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Occupancy Schedules for Energy Simulation in New prEN16798-1 and ISO/FDIS 17772-1 Standards

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Highlights

- Hourly schedules for occupant, lighting and appliance are reported.
- Heat emission from occupant body are discussed.
- Information for prEN16798-1 and ISO/FDIS 17772-1 occupancy schedule is reported.
- Average hourly schedule of usages underestimates the peak cooling demand.
- Detailed hourly schedules are required to estimate the annual cooling energy demand.

Abstract

This study reports the development of occupancy, lighting and appliance hourly schedules for new energy calculation input data standards. Developed schedules apply for 10 building categories which are described by one to three space categories, and include the separation between weekdays and weekends if needed. The approach used allowed to keep the full set of schedules compact and easy to implement in building energy simulation tools. The average values cab be used in monthly calculation tools. Occupant density values have local nature and occupancy patterns also depend on culture. The structure of the schedules, i.e. the way how the occupancy patterns are described, may be seen as an original result and its application has no geographical limitations. The main focus of the study was in the occupancy heat emission modeling and schedule development for prEN16798-1 and ISO/FDIS 17772-1 standards, supported by appliances and lighting schedules which are similarly needed as energy calculation input data. Hourly schedules allow to model occupant behaviour effects, for instance the peak cooling load in an office room was increased by factor of 1.1 to 1.3 compared to the use of constant average value. Single office schedule increased the delivered cooling energy by 8% compared to an open plan office schedule. The findings emphasize the importance of realistic schedules for specific categories of buildings.

Keywords

Occupant schedule; Lighting schedule; Appliance schedule; Occupant heat emission

Nomenclatures

EE, Energetic equivalent $(\frac{Wh}{\text{litre of } O_2})$

H, Height (m)

M, Metabolic rate (met)

P, Heat emission $\left(\frac{W}{m^2}\right)$

Q, Energy for calculated time period $\left(\frac{\text{kWh}}{m^2}\right)$

RH, Relative humidity (%)

RQ, Respiratory quotient (-)

W, Weight (kg)

W, External work (W)

$\mathrm{A}_{DU,}$ Body surface area (m^2)

f_{cl}, Clothing area factor (-)

h_c, Convective heat transfer coefficient $\left(\frac{\mathrm{W}}{\mathrm{m^2K}}\right)$

I_{cl}, Clothing insulation (It is an average including uncovered parts of the body) $\left(\frac{\mathrm{m^2K}}{W}\right)$

k, Usage rate during operation hours (-)

$Moisture_{Occ}$, Humidity generation from body $\left(\frac{kg}{\mathrm{s}}\right)$

p_{pw}, Partial water vapor pressure (Pa)

p_{ws}, Water vapor saturation pressure (Pa)

$Q_{Convection}$, Convection heat loss (W)

Q_{Sweat}, Heat loss through sweating (W)

Q_{Total}, Total heat loss (W)

$Q_{Radiation}$, Radiation heat loss (W)

Q_{Vapor}, Vapor heat loss (W)

T, ambient temperature (K)

t_a, Air temperature (°C)

t_{cl}, Clothing surface temperature (°C)

t_{op}, Operative temperature (°C)

t_r, Mean radiant temperature (°C)

t_{sk}, Mean skin temperature (°C)

V_{ar}, Relative mean air velocity $(\frac{\text{m}}{\text{s}})$

V_{CO_2}, Carbon dioxide generation rate $\left(\frac{\text{liter}}{\text{h}}\right)$

V_{O_2}, Oxygen consumption rate $\left(\frac{\text{liter}}{\text{h}}\right)$

τ, Length of the calculation period (h) (8760 h for a year)

τ_d, Operation hours in a day (h)

τ_w, Operation days in a week (day)

1. Introduction

European buildings are considered as leading energy using sector that account for 40% of the total final energy use. Residential buildings accounts two thirds of consumption at the European Union (EU) level [1]. Space conditioning is the most dominating one for energy use in residential buildings followed by the lighting, appliance and domestic hot water (DHW) use [1]. Heating, Ventilation, and Air condition (HVAC) systems use 50% of total energy followed by lighting, appliances, and DHW in the non-domestic building sector [2]. Aiming to achieve the energy efficiency targets in buildings, Energy Performance of Building Directives (EPBD) requires all new public buildings and other buildings to be transformed into nearly zero energy buildings by 2018 and 2020, respectively [3].

The key contributors of energy usages in a building are space conditioning, technical system operation, lighting, and appliances facilities, etc. All those end uses are oriented to the occupant presence schedule and the user behavior in occupied space. Sekki et al. [4] explored the energy usages in Finnish daycare centers and school buildings and found the variation of energy usages due to the occupancy presence schedule and space efficiency (m^2/person). Kurnitski et al. [5] estimated the ventilation need in low occupancy industrial buildings. The study proposed that 1.0 l/m^2 s would be relevant general design value for such type of studied buildings due to the low occupancy and low polluting materials [5]. Many studies also acknowledged that the diversity of user behavior has an illustrious effect on energy consumption, while keeping other building parameters [6-8] alike. Haldi and Robinson [9] found a large impact of occupant behavior on heating and cooling need, lighting and appliance, and building control system. Additionally, occupancy presence pattern and flows may result in different energy consumption, though all building parameters are alike. Yun et al. [10] conducted a survey in four office spaces, where three spaces of those were occupied by the post graduate students and one was occupied by the administrative employees. The occupied hours in administrative space were the shortest one among other spaces. The study resulted in 50% of lighting energy increment due to the change of occupancy presence schedule in observed spaces.

Occupancy schedule is a crucial factor that can change the HVAC load in buildings. Based on the occupancy level Ahmed et al. [11] studied the indoor climate condition and the energy performance of Finnish low energy buildings. The average occupancy rate was 0.55 during office hours, which offered 7-8% of primary energy savings for Demand Controlled Ventilation (DCV) system compared to Constant Air Volume (CAV) system [11]. In the similar context, Oldewurtel et al. [12] considered the homogeneous and alternative occupancy patterns in a Model Predictive Control (MPC) framework to estimate the energy saving potential in Swiss office buildings, which was equipped with integrated room automation facilities. The simulation results with alternative patterns showed up to 50% of higher energy saving potentials compared to homogeneous occupancy pattern [12]. Plug loads such as personal computer, telephone, outlying office devices are interconnected to occupancy presence schedule. Mahdavi et al. [13] used the long term monitored data in Vienna office building to develop the correlation between occupant presence and usage of plug loads. The study found the influences of the occupant presence probability on plug loads energy usage. Also, lighting accounted for 5-15% of total energy consumption in industrial countries depending on user presence and behavior [14]. Also, energy need for DHW is equally important in residential and commercial buildings. Ahmed et al. [15] provided the hourly DHW profiles for different occupant groups in Finnish residential buildings. The variations of hourly DHW consumption were observed during weekdays, weekends [15] as well as different months of a year [16], which ensured different occupancy presence patterns in residential buildings. Moreover, actual occupancy profiles in different building categories are equally important for the development of energy management systems (EMS). Korkas et al. [17] accounted the heterogeneous pattern of occupancy in grid connected EMS, which could optimize both energy cost and thermal comfort. Also, occupancy behaviors towards energy consumption and impact of weather condition on grid connected EMS were briefly illustrated [18].

Poor understanding of occupant influences can lead higher energy variations between on-site building performance and predicted performance at design phase. Chang and Tianzhen [19] found occupancy schedule as the most influential factor, which caused differences between the measured and simulated results. Proper energy management in buildings and efficient operation of building systems could be achievable by means of having occupancy schedule in buildings. As of today, many occupancy prediction models are proposed in literature body.

Different approaches, namely deterministic and probabilistic approach were used to determine the effect of occupancy rate, occupant presence schedule, and user behavior on energy consumption [20, 21]. In deterministic approach, multiple drivers can be linked up with one or multiple outputs. For instance, internal heat gain from occupants can be easily determined based on the exact occupant numbers. On the other hand, probabilistic approach is based on the statistical algorithm to predict the probability of an event, that models the occupant's activities such as windows opening [10, 22, 23], lighting control [24, 25]. Aert et al. [26] proposed a deterministic approach, based on Belgium time use data set. The data comprised with detailed activities of 6400 individuals from 3474 Belgium households. By using hierarchical clustering, the study found seven profiles that accounted three possible states, namely: (1) at homes and awake, (2) sleeping, and (3) absent. Those profiles highly distinguished the general behaviors and were simple to implement in building simulation tools. However, predictability and lack of interaction in between the occupants and building were found as the key limitations of this approach.

Similarly, the study [27] presented the occupancy pattern in UK households with a 10 minutes' time resolution. The analysis also accounted the weekdays, and weekend occupant variations in households. Based on the UK 2000 Time Use Survey (TUS) data sets, it proposed a method that could determine the active occupant number in household at a given time [27]. In addition, the study [28] analyzed the statistical properties of occupancy rate in single person occupied offices. It focused on the intermediate periods between the presence and absence of the occupants. A probabilistic model could forecast the occupancy sequences in a single person occupied office. The model could explain the occupant behavior, but it was not suitable to clarify the long absence behavior of occupant [28]. To orient the previous study, Chang and Hong [19] collected statistical data from 200 cubical offices. The proposed mathematical model could explain the occupant presence pattern as well as the probability distribution of the number of absences and respective absences duration. The model could illustrate the occupancy status in single person occupied offices and cubical offices, however, it could not justify the occupant status in offices where multiple occupants were available.

Occupancy schedule in non-domestic buildings such as shopping mall, school, university, industrial hall, etc. are very complex due to the variety of activities. Studies discussed above reveal that the dynamic occupancy models of those buildings require a large amount of input data and that cannot be seen suitable for the implementation in common building energy simulation. Therefore in this study occupancy models were not implemented and typical occupancy patterns national data collected by REHVA Technology and Research Committee, mostly relying on existing literature and codes [27, 29, 30] was used.

The main objective of this study was to prepare simplified hourly occupancy profiles for different categories of buildings that can be used as input data in energy simulation tools. In addition, corresponding lighting and appliance schedules which are similarly needed in energy simulation were constructed. Heat emissions from occupants were calculated for summer and winter conditions and for activities and occupant ages typical in studied 10 building categories. The results were combined with occupancy patterns data from existing literature and codes and the structure of energy simulation space categories and corresponding schedules was developed. The number of space categories was kept in minimum in order to be suitable for typical low resolution zoning in energy simulation. In residential buildings, only one space category set of schedules and in office buildings three space categories were used to allow the grouping of similar rooms to larger zones what is needed for faster modeling and simulations. Developed profiles are therefore intended to be used in a building or large zone of similar category of rooms with the exception of single office and meeting rooms, and there is no need for room by room zoning including all rooms. Being standard hourly level occupancy and other internal heat load schedules they allow to study occupant behaviour effects and may be easily modified to describe other pattern variations under interest.

2. Method

This section reports the internal heat load calculation method, background information of profiles, study assumptions, and profiles application in building level. These detail information is used to develop the occupancy schedule modelling at new prEN16798-1 and ISO/FDIS 17772-1 Standards.

2.1 Internal heat load

This section explains the body surface area, dry and total heat loss from occupant body and heat load form lighting and equipment. Body surface area is a unique parameter, which depends on individual height and weight. It is considered as the most significant parameter that shows a large variation among occupants even though having a similar amount of muscular activity. Also, heat loss by skin diffusion, radiation, and convection depend on body surface area. The body surface area is calculated with Du Bois formula, which considers 50 percentile weight and height of corresponding age and sex [29]

$$\mathrm{A}_{DU} = 0.202 * W^{0.425} * H^{0.725} \quad (1)$$

With $\mathrm{A}_{DU,}$ body surface area, (m^2), $W,$ weight, (kg), $H,$ height, (m)

Heat emission from human body depends on many factors such as room temperature, mean radiant temperature, relative humidity, air velocity, body surface area, metabolic rate, clothing insulation, etc. The set point of indoor air temperature, mean radiant temperature, relative humidity, relative air velocity, and clothing insulation account the seasonal variations which may change the heat emission from the occupant body. Table 1 reports different parameters to calculate the heat emission from occupant body during summer and winter seasons.

Insert Table 1 here

In the same fashion, metabolic rates are associated with the human activities. The energy release from the metabolism is subjected to the muscular activity. Metabolism is measured in Met units; 1.0 Met is equivalent to 58.15 W/m^2 per body surface area. To determine the dry and total heat losses from occupant body, metabolic rates of studied building categories are reported in Table 1 in data article [30]. Likewise, higher physical activity can produce more heat that needs to be lost for keeping a thermal equilibrium state of the body. Total heat loss from the occupant body is the sum of convection heat loss, radiation heat loss, vapor heat loss, and sweat heat loss, whereas dry heat loss is the sum of convection heat loss and radiation heat loss from occupant body. All equations shown in below are derived from the general format of [31, 32]:

$$Q_{Convection} = \{f_{cl}\, h_c(t_{cl} - t_{op}) + 0.0014\, M(34 - t_{op})\} \tag{2}$$

$$Q_{Radiation} = 39.6\,.\,10^{-9}\, A_{DU}\, f_{cl}\, \{(t_{cl} + 273)^4 - (t_r + 273)^4\} \tag{3}$$

$$Q_{Vapor} = A_{DU}\, [3.05\,.\,10^{-3}\, \{5733 - 6.99\,(M - W) - p_{pw}\} + 1.72\,.\,10^{-5}\, M\, (5867 - p_{pw})] \tag{4}$$

$$\frac{t_{sk} - t_{cl}}{I_{cl}} = 3.96\,.\,10^{-8}\ f_{cl}\, [(t_{cl} + 273)^4 - (t_r + 273)^4\}] + f_{cl}\, h_c\, (t_{cl} - t_a) \tag{5}$$

$$h_c = \begin{cases} 2.38\,(t_{cl} - t_a)^{0.25} & for\ 2.38\,(t_{cl} - t_a)^{0.25} > 12.1\sqrt{V_{ar}} \\ 12.1\sqrt{V_{ar}} & for\ 2.38\,(t_{cl} - t_a)^{0.25} \leq 12.1\sqrt{V_{ar}} \end{cases} \tag{6}$$

$$f_{cl} = \begin{cases} 1.0 + 1.29\, I_{cl} & for\ I_{cl} < 0.078\, m^2K/W \\ 1.05 + 0.645\, I_{cl} & for\ I_{cl} \geq 0.078\, m^2K/W \end{cases} \tag{7}$$

$$t_{sk} = 35.7 - 0.028(M - W) \tag{8}$$

$$p_{ws} = \frac{e^{(77.3450 + 0.0057T - \frac{7235}{T})}}{T^{8.2}} \tag{9}$$

$$p_{pw} = \frac{RH}{p_{ws}} \times 100 \tag{10}$$

$$Q_{Total} = A_{DU}\,.\,M \tag{11}$$

$$Q_{Sweat} = Q_{Total} - Q_{Convection} - Q_{Radiation} - Q_{Vapour} \tag{12}$$

With $Q_{Convection}$, convection heat loss, (W), $Q_{Radiation}$, radiation heat loss, (W), Q_{Vapor}, vapor heat loss, (W), Q_{Total}, total heat loss, (W), Q_{Sweat}, heat loss through sweating, (W), A_{DU}, body surface area, (m^2), M, metabolic rate, (met), W, external work, (W), t_a, air temperature, (°C), t_r, mean radiant temperature, (°C), t_{op}, operative temperature, (°C), t_{cl}, clothing surface temperature, (°C), t_{sk}, mean skin temperature, (°C), I_{cl}, Clothing insulation (It is an average including uncovered parts of the body), $\left(\frac{\mathrm{m^2K}}{W}\right)$, f_{cl}, Clothing area factor, (-), h_c, Convective heat transfer coefficient, $\left(\frac{\mathrm{W}}{\mathrm{m^2K}}\right)$, p_{ws}, water vapor saturation pressure, (Pa), p_{pw}, partial water vapor pressure, (Pa), V_{ar}, relative mean air velocity, $(\frac{\mathrm{m}}{\mathrm{s}})$, RH, relative humidity, (%), T, ambient temperature, (K).

In the similar context, solar, appliance and lighting are also considered as internal heat sources in a building. Solar heat gain is a dynamic process and depends on many influencing factors, i.e. weather, building dimension, windows and envelope properties, solar radiation, etc. Due to the high complexity, this study overlook the solar heat gain and discuss only the heat load association from appliance and lighting. Heat emission from internal heat gains for a given period (equals with energy use for lighting and appliances, except in the case of washing machines where heat gain is smaller because of waste water to sewage) is calculated as [33]

$$Q = k\ \frac{P}{1000}\ \frac{\tau_d}{24}\ \frac{\tau_w}{7}\ \tau \tag{13}$$

With, Q, energy for calculated time period, $(\frac{\mathrm{kWh}}{m^2.})$, k, usage rate during operation hours, (-), P, heat emission, $(\frac{W}{m^2.})$, τ_w, operation days in a week, (day), τ_d, operation hours in a day, (h), τ, length of the calculation period (h) (8760 h for a year).

2.2 Background information and assumption

This section introduces some background information of proposed profile. Also, building operation hour, occupant density, humidity generation, CO_2 generation from occupant, indoor temperature and relative humidity set points, ventilation rate, DHW, and illuminance level are briefly discussed here. The building operation hours and usages factor are developed from Finnish, Estonian and ASHRAE standard building code [34-36]. Also, set points for room temperature, ventilation rate, and relative humidity are presented according to prEN 16789-2 standard [37]. In addition, lighting facilities at different categories of building are varied depending on task type. Thus, the listed Lux-values are also simplified.

Furthermore, occupants are the key source of CO_2 and humidity generation in indoor environment. The CO_2 and humidity generation can be calculated by using the following equations [38].

$$\mathrm{RQ} = \frac{V_{CO_2}}{V_{O_2}} \tag{14}$$

$$\mathrm{EE} = \{(0.23\ RQ + 0.77) * 5.88\} \tag{15}$$

$$\mathrm{M} = EE\ *\ V_{O_2}\ *\ \frac{1}{A_{Du}} \tag{16}$$

$$Humidity_{Occ} = \frac{Q_{Vapor} + Q_{Sweat}}{2430000} \tag{17}$$

With, RQ, respiratory quotient, (-), EE, energetic equivalent, $(\frac{Wh}{\text{litre of O}_2.})$, V_{O_2}, oxygen consumption rate, $(\frac{\text{liter}}{\text{h}})$, V_{CO_2}, carbon dioxide generation rate, $(\frac{\text{liter}}{\text{h}})$, A_{DU}, body surface area, (m^2), M, metabolic rate, (met), $Moisture_{Occ}$, humidity generation from body, $(\frac{kg}{\text{s}})$, Q_{Vapor}, vapor heat loss, (W), Q_{Sweat}, heat loss through sweating, (W).

2.3 Simulation example

To estimate the impact of occupancy schedules, i.e. Office main, Office single 1, Office single 2, Office average on internal load and energy use of a building, this study has conducted dynamic simulations. A well validated indoor climate and energy simulation tool, namely IDA-ICE is used which is developed by EQUA Simulations AB [39]. IDA-ICE tool uses equations 2 to 12, which are included in the zone model of IDA-ICE and reported in [40], to estimate the heat gain from occupant body. A reference office building with multiple zones are modelled (Fig. 1). To obtain the impact of proposed profiles in building energy efficiency, the model considers the envelope properties, windows properties, temperature set points, occupant density, lighting, and equipment unit load, building operation hours according to Finnish building code which are shown in Table 2 and Table 3 [33]. Office main, Office single 1, Office single 2, Office average occupancy schedule are considered as main input variable. In addition, respective lighting, and equipment schedule for Office main, Office single 1, Office single 2, Office average are also taking into account. Ventilation rate, clothing insulation, metabolic rate, lighting and equipment power, illuminance level and convective heat from lighting are also accounted for this study.

Hourly weather data from Helsinki-Vantaa Test Reference Year (Vantaa TRY2012) [41, 42] is used to calculate the peak heating and cooling power, as well as respective annual energy use. The office building operation hours are set from 7:00 to 18:00 from Monday to Friday. The building plan, elevation, and 3D model are shown in Figure 1.

Insert Table 2 here

Insert Table 3 here

Insert Figure 1 here

3. Result and discussion

This section reports the internal heat load from occupant, lighting, and appliance. We also propose the building usage hourly profiles details related to occupant, appliances, and lighting for different categories of building. Moreover, the application of profiles in building simulation tools shows the effect of internal heat load on the building energy use.

3.1 Internal load

Internal heat loads in a building is associated with occupant, lighting, and appliances. Among those, occupant presence and respective heat generation from occupant in different building categories are considered as a dynamic variable. Higher variations of body surface area of occupants occur in day care centers, kinder gardens and schools compared to other building categories, mainly occupied by adults (detached house, apartment building, office building, departmental store, hotel restaurant, sport hall, and hospital). The differences of body surface area need to be accounted, otherwise in these building categories heat gains are overestimated. With Du Bois formula (equ.1) the body surface area is calculated, which is shown in Table 2 and Table 3 in data article [30]. Also, it is assumed that the occupant in other buildings except day care centers, kinder gardens, and schools are adult and average body surface area are shown in Table 4. Body surface area influences the heat loss by means of radiation, convection, and evaporation from occupant body. Heat losses from occupant body depend on different parameters. Input parameters in Table 1, Table 2, Table 3 in data article [30] and Table 1 are used to determine the heat loss from occupants during summer and winter. Heat losses by means of convection, radiation, vapor, sweat during summer and winter are given in Table 5 and Table 6 in data article [30]. The obtained dry and total heat loss are shown as the contribution of heat load from occupant. The simplification form of Table 1, Table 2, Table 3, Table 5, Table 6 and Table 7 in data article are shown in Table 4 [30].

Insert Table 4 here

Building operation hours and average loads from occupant, lighting and appliance for energy calculation are presented in the Table 5. The operational hours for different categories of buildings follows ASHRAE standard [36]. The building usage rates are calculated from the average of usage rates of building during operational hours. Humidity generation from occupant body and CO_2 generation from occupant breathing are also described for building types covered by EPBD.

Insert Table 5 here

The usage rates and load value for corresponding buildings can be used in all rooms and zones for energy calculation. Dry heat load, total heat load, and occupancy rate are considered as the basic information for energy simulation tools. It helps to estimate the HVAC load for a building. Also, the humidity and CO_2 generation can be used for sizing the ventilation system. The unit load of lighting depends on the installed power, control system and daylighting utilization factor. The values for lighting can be used if detailed information for lighting system is not available.

The hourly usage schedules for occupancy, lighting and appliance are not similar, thus, separate profiles are presented in Table 6, Table 7, and Table 8. Also, variation of usage schedules seems different during weekdays and weekend. The corresponding load value in Table 5 will multiply with the hourly usage schedules of occupancy, lighting, and appliance for energy calculation. Furthermore, the schedule for occupancy, lighting and appliances show remarkable differences in residential buildings. For some non-residential building cases, similar usage schedules for occupancy, lighting, and appliance can be used. Also, different weekdays and weekend usage schedules may be applicable for some categories of building.

Insert Table 6 here

Insert Table 7 here

Insert Table 8 here

The study treats the occupancy profiles as deterministic daily profiles. It shows the occupancy presence variation, which are in between 0 (absence) and 1 (presence). For the non-operational hours, i.e. after working hours, weekend the value is given as 0. The profiles are given as hourly basis and for some hours it shows a fractional value. For instance, occupancy rate during 8:00 – 9:00 hour is 0.2, indicates that the zone or building reaches 20% of full occupancy at 8:00 – 9:00 hour.

To develop the occupancy schedules for new prEN16798-1 and ISO/FDIS 17772-1 Standards, Table 4 to Table 8 are used. In addition, the set points of different parameters are collected from prEN 16798-1 Standard [37]. Input parameters and schedule reporting format of prEN 16798-1 are shown in Table 9.

Insert Table 9 here

The load values are different for different categories of building and similar load values are used in all zones in specific categories of building for energy simulation. Hourly schedule may change based on the room type and days in a week. In office building, three schedules are available namely: office, meeting room, single office. The usage patterns are different, but the average usage rates are equal.

The input values, set points and usage schedules for one space category, Office main, are shown in Table 10.

Insert Table 10 here

3.3 Simulation example

In total four occupancy schedules in office building are illustrated in Figure 2. The schedule of Office main and Office Single 1 are proposed for new prEN16798-1 and ISO/FDIS 17772-1 Standards. The schedule of Office Average is corresponded to the average value during occupied hours, i.e. Office main (Average schedule is 0.55) and Office single 1 (Average schedule is 0.55). The Office Average schedule (Constant schedule value of 0.55 during occupied hours) is included in this study to show the peak cooling load variation. To further illustrate the impact of peak cooling load, a reference profile, namely Office single 2 (Average schedule is 0.73) schedule is also included, though, it is not in the standard. The aim of inclusion is to show that the cooling system sizing requires more severe profile. Furthermore, the lighting and appliance schedule follow the similar schedule as occupant schedule for office building. However, for other buildings, i.e. residential building, detached house, apartment building, and restaurant have unique schedule for lighting, appliance and occupant.

Insert Figure 2 here

As schedule of occupant, lighting and appliance have impact on cooling load, the cooling need during 24 hours in a day (1st of August) are shown in Figure 3. The selection of this day is based on the maximum outdoor temperature (average temperature of a day) during a year. The average outdoor temperature and relative humidity were 25 °C and 59.3%, respectively.

Insert Figure 3 here

Figure 3 shows the different cooling power while keeping the maximum operative temperature of 25 °C. The peak cooling power for Office main, Office single 1, Office single 2, Office average are 1.51, 1.76, 1.78, 1.35 kW. This information has significant value while sizing the cooling system for office building. The results also show the importance of specific schedule for office building. For instance, peak cooling power for Office single 1 schedule is reported 16.5% higher compared to Office main schedule. The delivered heating energy with Office main, Office single 1, Office single 2, Office average schedule are 45.3, 46.4, 38.5, and 45,0 kWh/m^2/year, respectively. The average occupancy (Average of occupied hours) of each schedule, i.e. Office main, Office single 1, Office average is 0.55, whereas for Office single 2 schedule the average is 0.73. Higher average schedule value refers to higher internal heat load which keeps lower heating need. In contrast, annual cooling need is more depended on the hourly schedule. The annual cooling energy use with Office main, Office single 1, Office single 2, Office average schedule are 4.9, 5.3, 7.0 and 4.7 kWh/m^2/year, respectively. Though each schedule, i.e. Office main, Office single 1, Office average has equal average value of 0.55, the cooling need are increased by 4.3% and 12.8% for Office main and Office single 1 schedule, respectively compared to office average schedule. Also, cooling need for Single office 2 is increased by 48% compared to office average schedule due to the higher schedule average.

4. Conclusion

This study developed hourly occupancy profiles for new standards prEN16798-1 and ISO/FDIS 17772-1 schedules. These schedules apply for 10 building categories which are described by one to three space categories, and the separation between weekdays and weekends is provided for some specific cases. The approach used allowed to keep the full set of schedules compact and easy to implement in building simulation tools.

The background information for prEN16798-1 and ISO/FDIS 17772-1 occupancy schedule standards is reported. These hourly schedules for occupant, lighting and appliance can be used as input variables to conduct a dynamic energy simulations. For monthly energy calculations, an average values can be used. The following main conclusions can be drawn:

- This study shows the contribution of occupant emission, i.e. dry and total heat emission from occupant during summer and winter period (Table 4) as well as generation of humidity and CO_2 (Table 5);
- The hourly usages rate of occupancy, lighting and appliance are presented for main categories of buildings (Table 5) intended to be used for building energy simulation that aims to compliance assessment with energy performance minimum requirements according to EPBD.
- Hourly schedules for occupancy, lighting and appliances allow to study the effects of occupant behavior on peak cooling power (kW), peak heating power (kW), and heating and cooling energy use (kWh/m^2/year) (Table 6, Table 7, Table 8).
- The format of the schedules data used in prEN16798-1 and ISO/FDIS 17772-1 standards is justified (Table 9) and one example is provided (Table 10).
- Energy simulation example conducted illustrates that constant or average office schedules failed to predict the actual cooling need. Compared to average schedule hourly Office main and Office single schedules increased the peak cooling load by 12% and 30% respectively.
- Energy simulation example resulted in 8.0% of higher delivered cooling energy (kWh/m^2/year) and 16.5% of higher peak cooling power (kW) for simulated office floor with Office single schedule compared to Office main schedule. These findings emphasize the importance of realistic hourly schedule for different categories of buildings.

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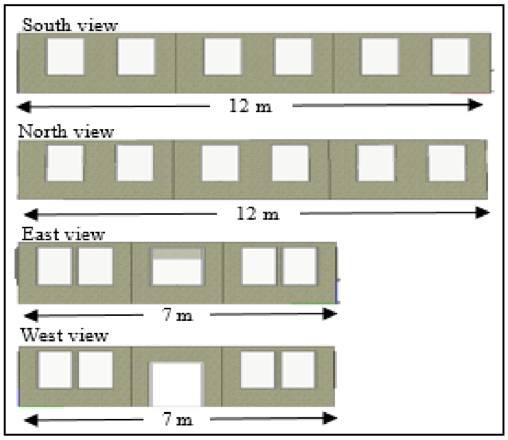
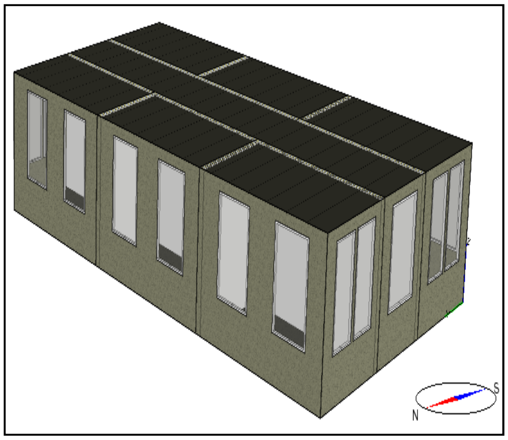
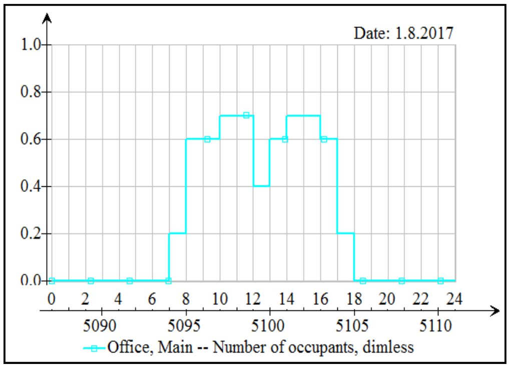
Figures

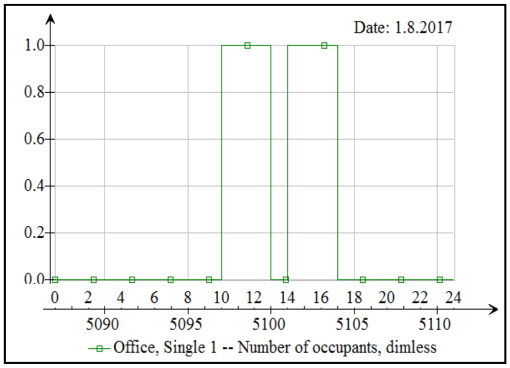




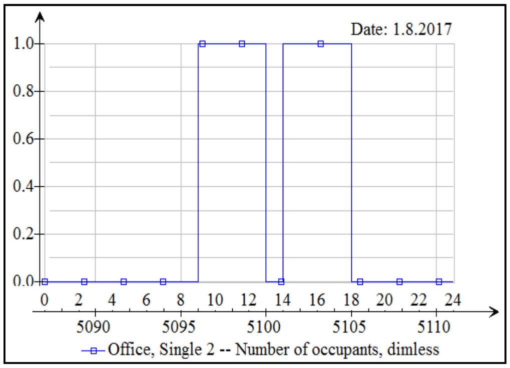
(a) (b)

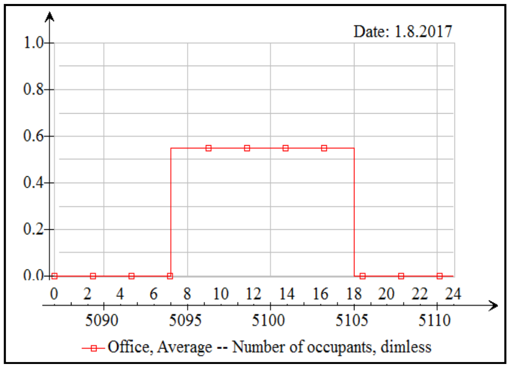
Figure. 1. Simulated building (a) Design views and (b) 3D model. Dimensions are given in meters.





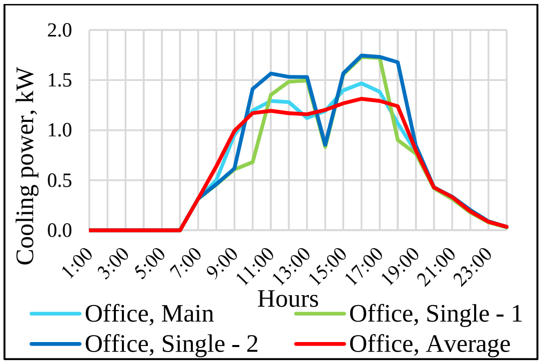
(a) (b)



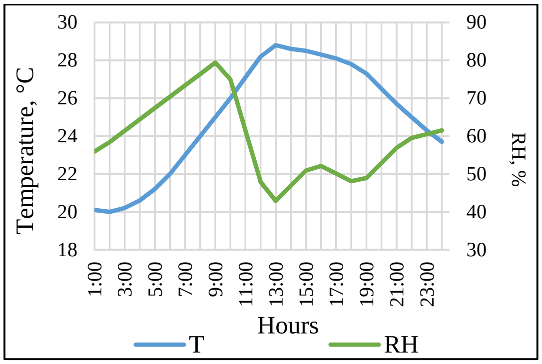


(c) (d)

Figure 2. Occupants schedule for a) Office, Main b) Office, Single 1 c) Office, Single 2 d) Office, Average.



(a)



(b)

Figure 3. a) Peak cooling power for different occupant schedule, b) Temperature and relative humidity during 24 hours in a day (1st of August)

Tables

Table 1. List of input parameters for heat emission calculation from occupant.

	Range [27]	Summer	Winter
Temperature, °C	18-27	24.5	22.0
Mean radiant temperature, °C	18-27	24.5	22.0
Operative temperature, °C	18-27	24.5	22.0
Relative humidity, %	20-80	60.0	30.0
Clothing insulation, *clo*	0.3-1.4	0.6	1.0
Air velocity, m/s	0.05-0.2	0.15	0.1

Table 2. Building envelope input parameters.

Building envelope part	Thermal transmittance (U-value), W/(m^2 K)	Total area, m^2
Ground floor area	0.2	84.0
External walls	0.17	114.0
Roof	0.13	84.0
Windows	0.8	33.3
Doors	1.5	2.4

Table 3. Energy simulation input parameters.

Parameter	Value
Operation hour	7:00-18:00
Occupant density, m^2/person	10.0
Metabolic rate, met	1.2
Temperature range, °C	20-26
Relative humidity range, %	25-60
Ventilation rate, l/(s m^2)	2.0
Specific fan power (system), kW/(m^3/s)	1.5
Ventilation heat exchanger temperature efficiency, %	74.0
Lighting power, W/m^2	12.0
Equipment, W/m^2	12.0
Illuminance in working area, lux	450 - 500

Table 4. Summary of dry and total heat loss from occupant's body.

Building type	Metabolic rate. M	Body surface area. A_{DU}	Summer		Winter		Average	
			Q_{Dry}	Q_{Total}	Q_{Dry}	Q_{Total}	Q_{Dry}	Q_{Total}
	met	m^2	W	W	W	W	W	W
Detached house	1.2	1.80	82.8	118.3	77.8	118.3	80.3	118.3
Apartment building	1.2	1.80	82.8	118.3	77.8	118.3	80.3	118.3
Office building	1.2	1.80	82.8	118.3	77.8	118.3	80.3	118.3
Departmental store	1.6	1.80	77.6	157.8	74.2	157.8	75.9	157.8
Hotel	1.2	1.80	82.8	118.3	77.8	118.3	80.3	118.3
Restaurant	1.2	1.80	82.8	118.3	77.8	118.3	80.3	118.3
Sport, terminal, theatre	1.6	1.80	77.6	157.8	74.2	157.8	75.9	157.8
School	1.2	1.68	72.3	116.9	76.7	116.9	74.5	116.9
Daycare center (2-4 yr.)	1.0	0.66	29.5	38.3	30.9	38.3	30.2	38.3
Kinder garden (5-6 yr.)	1.39	0.77	32.0	62.1	34.5	62.1	33.2	62.1
Hospital	1.2	1.80	82.8	118.3	77.8	118.3	80.3	118.3

Meeting room	1.2	1.80	82.8	118.3	77.8	118.3	80.3	118.3
Classroom	1.2	1.80	82.8	118.3	77.8	118.3	80.3	118.3
Computer-classroom	1.2	1.80	82.8	118.3	77.8	118.3	80.3	118.3

Table 5. Operation hours and average loads for energy calculation.

Building type	Operation hours			Occupancy						Appliances		Lighting	
				Usage rate	Total	Dry	Humidity generation	CO_2 generation	Occup. rate	Usage rate	Unit load	Usage rate	Unit load
	Time	h/24h	d/7d		W/m^2	W/m^2	g/(m^2.h)	l/(m^2.h)	m^2/per.		W/m^2		W/m^2
Detached house	00:00-00:00	24	7	0.60	2.8	1.9	1.41	0.44	42.0	0.60	2.4	0.10	8.0
Apartment building	00:00-00:00	24	7	0.60	4.2	2.9	2.12	0.66	28.0	0.60	3.0	0.10	8.0
Office building	07:00-18:00	11	5	0.55	7.0	4.7	3.53	1.1	17.0	0.55	12.0	0.55	12.0
Department store	08:00-21:00	13	7	0.60	9.3	4.5	3.53	1.1	17.0	1.00	1.0	1.00	20.0
Hotel	00:00-00:00	24	7	0.58	5.6	3.8	2.67	0.90	21.0	0.37	1.0	0.41	8.0
Restaurant	06:00-00:00	18	7	0.46	19.7	13.4	9.84	3.07	6.0	0.20	4.0	0.64	20.0
Sport, terminal, theatre	08:00-22:00	14	7	0.60	9.3	4.5	7.11	1.11	17.0	0.00	0.0	1.00	14.0
School	08:00-17:00	9	5	0.50	21.3	13.6	11.11	3.46	5.5	0.50	8.0	0.50	15.0
Daycare center	07:00-19:00	12	5	0.40	15.5	8.3	15.79	4.92	4.0	0.40	4.0	0.40	15.0
Hospital	00:00-00:00	24	7	0.54	10.8	7.3	5.19	1.71	11.0	0.62	4.0	0.62	9.0

Table 6. Hourly schedules of occupancy for energy calculation.

Time	Residential	Office main	Single office	Meeting room	School	Day care center	Sport, terminal, theatre	Restau--rant	Departmental store		Hotel		Hospital	
									WD	WE	WD	WE	WD	WE
00:00-01:00	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.9	0.8	0.4	0.4
01:00-02:00	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.9	0.8	0.4	0.4
02:00-03:00	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.9	0.8	0.4	0.4
03:00-04:00	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.9	0.8	0.4	0.4
04:00-05:00	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.9	0.8	0.4	0.4
05:00-06:00	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.9	0.8	0.4	0.4
06:00-07:00	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.7	0.7	0.4	0.4
07:00-08:00	0.5	0.2	0.0	0.0	0.0	0.4	0.0	0.4	0.0	0.0	0.4	0.6	0.5	0.5
08:00-09:00	0.5	0.6	0.0	0.5	0.6	0.8	0.6	0.4	0.1	0.1	0.4	0.5	0.6	0.6
09:00-10:00	0.1	0.6	1.0	0.8	0.7	0.8	0.6	0.4	0.3	0.3	0.2	0.4	0.8	0.6
10:00-11:00	0.1	0.7	1.0	0.9	0.6	0.3	0.6	0.2	0.3	0.6	0.2	0.4	0.8	0.6
11:00-12:00	0.1	0.7	1.0	0.8	0.4	0.3	0.6	0.5	0.7	0.9	0.2	0.3	0.8	0.6
12:00-13:00	0.1	0.4	0.0	0.0	0.3	0.8	0.6	0.8	0.6	1.0	0.2	0.3	0.8	0.6
13:00-14:00	0.2	0.6	1.0	0.7	0.7	0.1	0.6	0.7	0.5	0.9	0.2	0.3	0.8	0.6

14:00-15:00	0.2	0.7	1.0	0.8	0.6	0.1	0.6	0.4	0.6	0.7	0.2	0.3	0.8	0.6
15:00-16:00	0.2	0.7	1.0	0.8	0.4	0.4	0.6	0.2	0.6	0.5	0.3	0.3	0.8	0.6
16:00-17:00	0.5	0.6	0.0	0.7	0.2	0.3	0.6	0.3	0.9	0.3	0.5	0.4	0.8	0.5
17:00-18:00	0.5	0.2	0.0	0.0	0.0	0.3	0.6	0.5	0.9	0.3	0.5	0.5	0.6	0.5
18:00-19:00	0.5	0.0	0.0	0.0	0.0	0.3	0.6	0.8	1.0	0.5	0.5	0.5	0.5	0.5
19:00-20:00	0.8	0.0	0.0	0.0	0.0	0.0	0.6	0.8	0.9	0.5	0.7	0.6	0.5	0.4
20:00-21:00	0.8	0.0	0.0	0.0	0.0	0.0	0.6	0.8	0.7	0.5	0.7	0.6	0.4	0.4
21:00-22:00	0.8	0.0	0.0	0.0	0.0	0.0	0.6	0.5	0.0	0.0	0.8	0.8	0.4	0.4
22:00-23:00	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.9	0.8	0.4	0.4
23:00-00:00	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.9	0.8	0.4	0.4

Table 7. Hourly schedules of appliances for energy calculation.

Time	Residential	Office main	Single office	Meeting room	School	Day care center	Sport, terminal, theatre	Restau- -rant	Departmental store		Hotel		Hospital	
									WD	WE	WD	WE	WD	WE
00:00-01:00	0.5	0	0	0	0	0	0	0	0	0	0.2	0.2	0.5	0.5
01:00-02:00	0.5	0	0	0	0	0	0	0	0	0	0.2	0.2	0.5	0.5
02:00-03:00	0.5	0	0	0	0	0	0	0	0	0	0.2	0.2	0.5	0.5
03:00-04:00	0.5	0	0	0	0	0	0	0	0	0	0.2	0.2	0.5	0.5
04:00-05:00	0.5	0	0	0	0	0	0	0	0	0	0.2	0.2	0.5	0.5
05:00-06:00	0.5	0	0	0	0	0	0	0	0	0	0.2	0.2	0.5	0.5
06:00-07:00	0.5	0	0	0	0	0	0	0.13	0	0	0.62	0.3	0.5	0.5
07:00-08:00	0.7	0.2	0	0	0	0.4	0	0.15	0	0	0.9	0.62	0.7	0.45
08:00-09:00	0.7	0.6	0	0.5	0.6	0.8	0	0.18	1	1	0.43	0.9	0.9	0.63
09:00-10:00	0.5	0.6	1	0.8	0.7	0.8	0	0.21	1	1	0.43	0.62	0.9	0.63
10:00-11:00	0.5	0.7	1	0.9	0.6	0.3	0	0.26	1	1	0.26	0.29	0.9	0.63
11:00-12:00	0.6	0.7	1	0.8	0.4	0.3	0	0.29	1	1	0.26	0.29	0.9	0.63
12:00-13:00	0.6	0.4	0	0	0.3	0.8	0	0.27	1	1	0.26	0.29	0.9	0.63
13:00-14:00	0.6	0.6	1	0.7	0.7	0.1	0	0.25	1	1	0.26	0.29	0.9	0.63
14:00-15:00	0.6	0.7	1	0.8	0.6	0.1	0	0.23	1	1	0.26	0.29	0.9	0.63
15:00-16:00	0.5	0.7	1	0.8	0.4	0.4	0	0.23	1	1	0.26	0.29	0.9	0.63
16:00-17:00	0.5	0.6	0	0.7	0.2	0.3	0	0.26	1	1	0.26	0.29	0.6	0.52
17:00-18:00	0.7	0.2	0	0	0	0.3	0	0.26	1	1	0.51	0.43	0.6	0.52
18:00-19:00	0.7	0	0	0	0	0.3	0	0.24	1	1	0.51	0.51	0.6	0.4
19:00-20:00	0.8	0	0	0	0	0	0	0.22	1	1	0.49	0.49	0.6	0.4
20:00-21:00	0.8	0	0	0	0	0	0	0.2	1	1	0.66	0.66	0.6	0.4
21:00-22:00	0.8	0	0	0	0	0	0	0.18	0	0	0.7	0.7	0.6	0.4
22:00-23:00	0.6	0	0	0	0	0	0	0.09	0	0	0.35	0.35	0.6	0.4
23:00-00:00	0.6	0	0	0	0	0	0	0.03	0	0	0.2	0.2	0.4	0.4

Table 8. Hourly schedules of lighting for energy calculation.

Time	Residential	Office main	Single office	Meeting room	School	Day care center	Sport, terminal, theatre	Restau--rant	Departmental store		Hotel		Hospital	
									WD	WE	WD	WE	WD	WE
00:00-01:00	0	0	0	0	0	0	0	0	0	0	0.22	0.26	0.5	0.5
01:00-02:00	0	0	0	0	0	0	0	0	0	0	0.17	0.26	0.5	0.5
02:00-03:00	0	0	0	0	0	0	0	0	0	0	0.11	0.11	0.5	0.5
03:00-04:00	0	0	0	0	0	0	0	0	0	0	0.11	0.11	0.5	0.5
04:00-05:00	0	0	0	0	0	0	0	0	0	0	0.11	0.11	0.5	0.5
05:00-06:00	0	0	0	0	0	0	0	0	0	0	0.22	0.11	0.5	0.5
06:00-07:00	0.15	0	0	0	0	0	0	0.3	0	0	0.44	0.41	0.5	0.5
07:00-08:00	0.15	0.2	0	0	0	0.4	0	0.3	0	0	0.56	0.41	0.5	0.5
08:00-09:00	0.15	0.6	0	0.5	0.6	0.8	1	0.55	1	1	0.44	0.56	0.9	0.75
09:00-10:00	0.15	0.6	1	0.8	0.7	0.8	1	0.55	1	1	0.44	0.56	0.9	0.75
10:00-11:00	0.05	0.7	1	0.9	0.6	0.3	1	0.75	1	1	0.28	0.41	0.9	0.75
11:00-12:00	0.05	0.7	1	0.8	0.4	0.3	1	0.75	1	1	0.28	0.33	0.9	0.75
12:00-13:00	0.05	0.4	0	0	0.3	0.8	1	0.75	1	1	0.28	0.33	0.9	0.75
13:00-14:00	0.05	0.6	1	0.7	0.7	0.1	1	0.75	1	1	0.28	0.33	0.9	0.75
14:00-15:00	0.05	0.7	1	0.8	0.6	0.1	1	0.75	1	1	0.28	0.33	0.9	0.75
15:00-16:00	0.05	0.7	1	0.8	0.4	0.4	1	0.75	1	1	0.28	0.33	0.9	0.75
16:00-17:00	0.2	0.6	0	0.7	0.2	0.3	1	0.7	1	1	0.28	0.33	0.5	0.65
17:00-18:00	0.2	0.2	0	0	0	0.3	1	0.75	1	1	0.28	0.33	0.5	0.65
18:00-19:00	0.2	0	0	0	0	0.3	1	0.75	1	1	0.67	0.85	0.5	0.5
19:00-20:00	0.2	0	0	0	0	0	1	0.75	1	1	0.89	1	0.5	0.5
20:00-21:00	0.2	0	0	0	0	0	1	0.75	1	1	1	1	0.5	0.5
21:00-22:00	0.2	0	0	0	0	0	1	0.75	0	0	0.89	1	0.5	0.5
22:00-23:00	0.15	0	0	0	0	0	0	0.5	0	0	0.67	0.85	0.5	0.5
23:00-00:00	0.15	0	0	0	0	0	0	0.3	0	0	0.41	0.41	0.5	0.5

Table 9. Format of data table in prEN 16798-1 Standard [34].

	Parameter Office, landscaped	Value	Unit		Diversity factor for Energy calculation					
Operation time	Hour at day, START	T5	hour		Weekdays			Weekends		
	Hour at day, END	T5	hour		Occupants	Appliances	Lighting	Occupants	Appliances	Lighting
	Breaks, inside range		hours							
	days/week	T5	days							
	hours/day	T5	hours							
	hours/year	cal.	hours	h						
Internal gains	Occupants	T5	m^2/pers.	1						
	Occupants (Total)	T4	W/m^2	2						
	Occupants (Dry)	T5	W/m^2	3						
	Appliances	T5	W/m^2	4						
	Lighting	T5	W/m^2	5						
	Humidity generation	T5	g/(m^2 h)	6						
	CO_2 generation	T5	l/(m^2 h)	7						
Set points	Min T, op in unoccupied hours	[34]	°C	8						
	Max T, op in unoccupied hours	[34]	°C	9						
	Min T,op, heating/winter	[34]	°C	10						
	Max T, op, cooling/summer	[34]	°C	11						
	Ventilation rate (min.)	[34]	l/(s m^2)	12						
	Ventilation rate for CO_2 emission	[34]	l/(s m^2)	13						
	Max CO_2 concentration (above outdoor)	[34]	ppm	14						
	Min. relative humidity	[34]	%	15						
	Max. relative humidity	[34]	%	16						
	Lighting, illuminance in working areas		lux	17						
Other	Domestic hot water use		l/(m^2 yr.)	18						

19						
20						
21						
22						
23						
24						

Table 10. Input parameters, set point and usage schedules for Office main.

	Parameter Office, landscaped	Value	Unit
Operation time	Hour at day, START	7	hour
	Hour at day, END	18	hour
	Breaks, inside range	0	hours
	days/week	5	days
	hours/day	11	hours
	hours/year	2868	hours
Internal gains	Occupants	17	m^2/per.
	Occupants (Total)	7.0	W/m^2
	Occupants (Dry)	4.7	W/m^2
	Appliances	12	W/m^2
	Lighting		
	Humidity generation	3.53	g/(m^2 h)
	CO_2 generation	1.10	l/(m^2 h)
Set points	Min T, op in unoccupied hours	16	°C
	Max T, op in unoccupied hours	32	°C

	Diversity factor for Energy calculation					
	Weekdays			Weekends		
h	Occupants	Appliances	Lighting	Occupants	Appliances	Lighting
1	0	0	0	0	0	0
2	0	0	0	0	0	0
3	0	0	0	0	0	0
4	0	0	0	0	0	0
5	0	0	0	0	0	0
6	0	0	0	0	0	0
7	0	0	0	0	0	0
8	0.2	0.2	0.2	0	0	0
9	0.6	0.6	0.6	0	0	0

	Min T,op, heating/winter	20	°C
	Max T, op, cooling/summer	26	°C
	Ventilation rate (min.)	0.8	l/(s m^2)
	Ventilation rate for CO_2 emission	0.53	l/(s m^2)
	Max CO_2 concentration (above outdoor)	500	ppm
	Min. relative humidity	25	%
	Max. relative humidity	60	%
	Lighting, illuminance in working areas	500	lux
Other	Domestic hot water use	100	l/(m^2 yr.)

10	0.6	0.6	0.6	0	0	0
11	0.7	0.7	0.7	0	0	0
12	0.7	0.7	0.7	0	0	0
13	0.4	0.4	0.4	0	0	0
14	0.6	0.6	0.6	0	0	0
15	0.7	0.7	0.7	0	0	0
16	0.7	0.7	0.7	0	0	0
17	0.6	0.6	0.6	0	0	0
18	0.2	0.2	0.2	0	0	0
19	0	0	0	0	0	0
20	0	0	0	0	0	0
21	0	0	0	0	0	0
22	0	0	0	0	0	0
23	0	0	0	0	0	0
24	0	0	0	0	0	0